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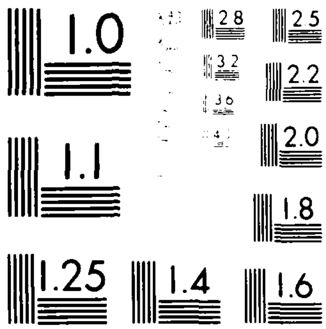

MICROCOPY RESOLUTION TEST CHART

AFTAC-TR-87-2

ST. KITTS DEPLOYMENT REPORT

JOSEPH P. NICHOLAS, CAPT, USAF

20 JULY 1987

FINAL REPORT.

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AIR FORCE TECHNICAL APPLICATIONS CENTER/TX
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SECURITY CLASSIFICATION OF THIS PAGE

AD-A186216

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFTAC-TR-87-2	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Air Force Technical Applications Center 6b. OFFICE SYMBOL (If applicable) TX	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Patrick AFB FL 32925	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.
11. TITLE (Include Security Classification) St. Kitts Deployment Report	
12. PERSONAL AUTHOR(S) Nicholas, Joseph P.	

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Final	FROM 4 Jul 86 TO 6 Jul 86	1987 July 20	21

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Hoax Hypervelocity Impact AFTAC-TR-87-2 Caribbean Deployment
03	02		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED X SAME AS RPT ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Capt Joseph P. Nicholas	22b. TELEPHONE NUMBER (Include Area Code) (305)494-5677 (AV854-5677) 22c. OFFICE SYMBOL TXN

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

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SUMMARY

Between 0000 and 0330, 28 June 1986, residents of Basseterre, St. Kitts, West Indies, reported an object fell from the sky. Later, a smoking hole was discovered in a nearby yard, prompting officials to request US assistance to investigate. Of prime concern was potential environmental or radiological safety. St. Kitts possessed no instrumentation or trained personnel to study the incident.

Upon US Embassy notification, 2 July 1986, Eastern Space and Missile Center dispatched the down range safety officer and simultaneously requested AFTAC assistance. AFTAC deployed an investigative team 4 July 1986.

The AFTAC team found a nearly vertical, 1.5m deep hole which showed evidence of burnt material within. The cause for the hole was not immediately apparent. The team took radiation measurements and determined the hole and its contents posed no radiological health hazard. In addition, the team collected a large number of rock and soil samples for later analysis.

The team reviewed all available data and determined that the hole had three possible causes: (1) meteorite, (2) a man-made reentering space object, or (3) a hoax or act perpetrated by persons unknown. The rock samples were further analyzed by the Aerospace Corporation and W. C. McCrone Associates. No unusual, non-island origin, material was identified from either sample analysis. The soil samples, after a circuitous route, were analyzed by the National Aeronautics and Space Administration's (NASA) Johnson Space Center, with similar findings.

This report concludes that the mystery hole was the result of a hoax.

ACKNOWLEDGEMENTS

This deployment and the subsequent analysis involved a large number of people and their time. In particular, the author acknowledges the following assistance: Dr Wendell Mendell and Dr Michael Zolensky, Johnson Space Center, National Aeronautics and Space Administration; Dr Henry Robitaille, The Land, EPCOT; Mr Jerry Bennett, Eastern Space and Missile Center Down Range Affairs; Maj Brinn Colenda, Antigua Air Station Commander and his wife; Ms Twyla Thomas, Division of Meteorites, Smithsonian Institution; Mr C. Wayne Young, Sandia National Laboratories, Albuquerque; Mr Grant Heiken, Los Alamos National Laboratory; Dr Michael Sulzer, Arecibo; Mr William Forrester, USDA; Lt Dale Benedetti, AFTAC/TN; Dr Francis Tsang, Idaho National Engineering Laboratory; and Dr Kenneth C. Herr, The Aerospace Corporation.

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SECTION I

INTRODUCTION

St. Christopher and Nevis (popular name St. Kitts) are part of the West Indies chain of islands located in the Caribbean Sea at approximately 17°N 62°W. The island is 65 square miles in area with a population of 35,000. St. Kitts received its independence from Great Britain in 1983.

On 2 July 1986, St. Kitts' Deputy Commissioner of Police Edward G. Hughes (acting Head of State, as the Prime Minister was out of country) contacted the US Embassy at Antigua to report that an "object" had apparently fallen to earth on 28 June and impacted on St. Kitts. Deputy Commissioner Hughes was concerned about potential environmental or radiological health hazards. The US Embassy Charge DuBose contacted Maj Brinn Colenda, Antigua Air Force Station Commander, for assistance. Maj Colenda subsequently contacted Eastern Space and Missile Center (ESMC) Down Range Affairs, Mr Jerry Bennett, for support. Maj Colenda also contacted the Command Post at US Space Command and was informed that no known space object had a decay prediction for the St. Kitts area during this time frame.

The St. Kitts Police Report is shown in Figure 1. The report provides an estimated time of occurrence as between 0230 and 0322, 28 June 1986. This is based on reports from residents who heard "what sounded like a bomb and a heavy impact crashing to the ground." The next day a smoking crater was discovered. The crater was in the College Street area of Basseterre, the capital of St. Kitts (see Figure 2).

After the request for assistance arrived at ESMC Down Range Affairs, it was passed to Col Albert Thomas, Eastern Test Range (ETR) Commander.

Criminal Investigation Department,
Basseterre, St. Kitts.
July 5th, 1986.

TO: D/Commissioner Of Police
FROM: No. 416 Sergt. Charles M.
SUBJECT: OBJECT FALLING FROM SKY

Sir,

I respectfully submit a report on the above mentioned subject.

In the early hours of the morning of Saturday 28th June, 1986 between 2.30 and 3.22 a.m. residents of Basseterre and in particular of the College Street area heard what sounded like a bomb and a heavy impact crashing to the ground and the dogs in those area started barking. When morning was cleared there was a strong burning scent coming from Mr. Oriel Claxton's premises adjacent to Blakency Flats.

Several persons want into the yard made a check and discovered a large hole in the ground. The hole was smoking and heated. For several days, or rather up to Wednesday 2nd July 1986, the day the matter was brought to the police attention, the hole still had some heat emanating from it. From the evidence and from all indication no one saw anything falling from the sky, all heard a sound like a bomb.

....

Respectfully Yours,
Meredith Charles Sergt. No. 416.

Figure 1. St. Kitts Police Report

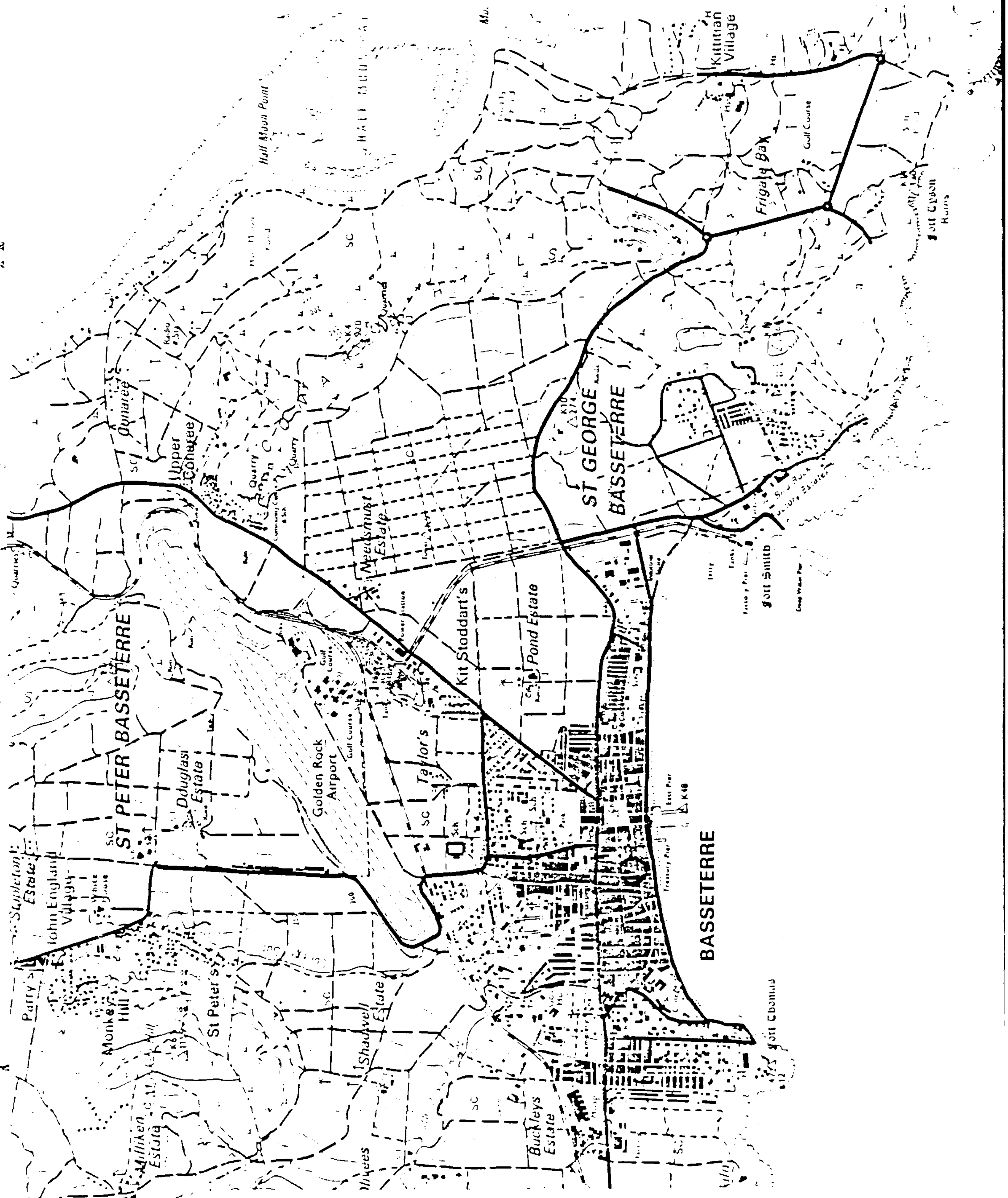


Figure 2. Map of Basseterre

Col Thomas dispatched the ETR safety officer, Capt Leonowich, and requested support from Col Thomas Ciambrone, AFTAC Vice Commander.

Col Ciambrone directed the formation of a quick-response team from the AFTAC Advanced Systems Directorate. Team members included Lt Col Joseph A. Angelo, Jr., Capt Donald Tipple and Capt Joseph Nicholas. Lt Col Angelo subsequently invited Dr William Ginsberg of EG&G, Las Vegas NV. Maj Brinn Colenda was to act as In-Country Coordinator for the operation. The AFTAC team arrived in St. Kitts 4 July 1986. Capt Leonowich arrived 8 July 1986.

Locally, both the "mystery hole" and the AFTAC team arrival were of extreme interest. The two island newspapers ran stories on the event. These articles are shown in Figures 3 and 4.

The team collected samples, made radiological measurements, and photographed the crater and environs 4-6 July.

MYSTERY HOLE CREATES SENSATION

Arriving in St. Kitts during the course of yesterday Friday were five (5) scientific investigators, who have been provided by the Government of the United States in response to a request initiated by Acting Commissioner of Police Hughes, following the discovery of a mystery hole in the Northern section of the yard of the premises of James A. Claxton & Sons in College Street Ghaut.

Speculation is rife among curiosity seekers as to the origin and nature of the circular hole which measures about 2 feet in diameter, and is approximately 8 feet deep, with burnt grass around the perimeter. Some say it was caused by a meteorite hurtling from the heavens beyond. Others say it may be linked to an explosion heard in the early hours of last Friday morning. Some declare they saw the hole steaming, as though with great heat. Still others contend that they have seen something black deep inside the hole, which appears to them to be getting progressively deeper.

When news of the discovery was reported to the Police on Wednesday, ZIZ Radio and Television hurried to the scene to broadcast a news flash, and to record this mystic phenomenon for posterity. Within minutes of the announcement, on Radio, dozens of children and adults could be seen flocking in College Street, and pushing and shoving to get into Blakeney Flats, which from its 4-storey Roof Top provided a vantage point for gazing down from what was felt to be a safe and convenient height on the gaping hole below.

Acting Commissioner Hughes told THE DEMOCRAT that contact was made with the US Embassy in Antigua for expert assistance , in order to satisfy a number of concerns. Is there any danger of radiation? What is in the hole, and what caused it? If anything is left of the thing which is responsible for the hole, how can this country adequately secure and preserve it?

The answers to these and other questions will no doubt be forthcoming, out of the research to be undertaken by the five (5) US Airforce Personnel. Major Colenda, who will coordinate the enquiry, is the Commander of the U.S. Air Station in Antigua. Dr. Joseph Angelo, who heads the Team, is accompanied by Dr. Irvin Ginsberg, of the U.S. Department of Energy, along with Joseph Nicholas and Donald Tipple. All hold scientific degrees.

Figure 3. From "The Democrat" of St. Kitts, 5 July 1986

THE LABOUR SPOKESMAN
Speech That Cannot Be Condemned

No 15 29th YEAR BASSETERRE, ST KITTS, W.I. SATURDAY, 5TH JULY, 1986 Price SIXTY CENTS

Meteorite Strike In College Street?

A smoking hole discovered at Central College Street, Basseterre, on Wednesday morning this week and believed to have been the result of a meteorite strike has given cause for much concern among the people of St. Kitts, especially residents of the College Street area.

The hole in the ground, estimated to be about 5 feet deep and 2 feet wide, was found on the northern side of the offices of the late James A. Claxton, a well-known local businessman and real estate agent.

The meteorite is said to have dropped between an unoccupied house on the Claxton premises and the Blakeney Flats on the north.

When local news reporters and a television crew arrived on the scene, the hole was still observed to be smoking and the dirt inside was also observed burning. By the next day (Thursday) the smoking had ceased.

It was obvious that this was not a man-made hole and the local experts at the Meteorological Unit at Golden Rock Airport have since confirmed this view.

One young man told our reporter that, sometime in the early hours of last Saturday morning (foreday), he saw a brilliant ball of light speeding across the sky, shedding a trail of sparks. Within a few seconds, said he, it vanished and then he heard a loud explosion.

For the next couple of days no one observed anything strange in the area until Wednesday morning when the smoke was seen coming from the area by some passers-by and young residents in the Ghaut.

They reportedly jumped over the fence and having observed the strange happening made a report to the Police.

Deputy Police Commissioner Edward G. Hughes told our reporter yesterday that the government has sought overseas assistance to help in the determination of the real cause of the crater in the ground.

He said a team of experts were expected to arrive from the United States of America late yesterday afternoon and that a U.S. Air Force Major B. Colenda had already arrived to co ordinate the programme. Tests are expected to be carried out sometime today (Saturday).

According to one renowned scientist in the United States of America, everyday the earth is bombarded by rocks from space called meteoroids.

Usually they are small and disintegrate with friction caused by their entry into the atmosphere. The result is the bright glow of their flight path, frequently seen streaking accross the night sky.

When this happens, he said, the meteoroid splits into meteors (shooting stars). If one of these meteors manages to penetrate all the way to earth's surface, it is known as a meteorite.

Scientists estimate that about seven (7) small meteorites bury themselves in the ground each year. Others dash into the sea.

Meteorites are composed either of stone or of an alloy of nickel and iron.

Scientists believe they probably come from somewhere within our solar system and are the remains of comets and asteroids - minor planets that have their orbits in the void between Jupiter and Mars.

This is the first time that such an incident has occurred in these parts and it is believed that the presence of Haley's Comet in the Northern Hemisphere in April this year could have influenced it.

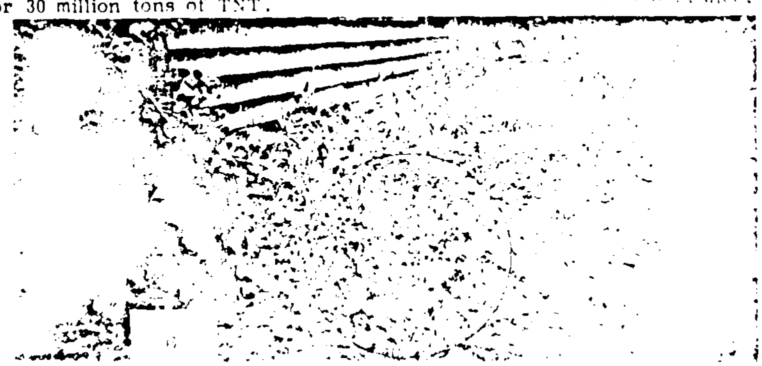
The biggest meteorite strike in recent times is reported to have occurred in Siberia in 1947. It reportedly weighed about 1,000 tons.

It broke up before it hit the earth at more than 90,000 miles per hour.

Twenty thousand years ago an iron nickel meteorite weighing an estimated 2 million tons, blasted a hole nearly a mile wide and 750 feet deep in the Arizona Desert. Its destructive force was bigger than a 30 megaton H-bomb or 30 million tons of TNT.

Hole in the ground. Some of the scorched grass around the hole are also visible.

Photo by Keithton France.

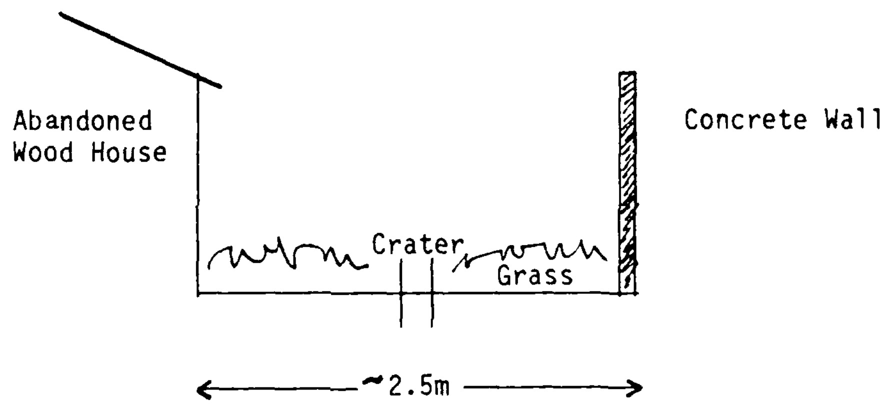


SECTION II

DATA COLLECTION

The crater was located between an abandoned home and a concrete wall, as indicated in Figure 5. These two "boundary" walls were almost due north and south of the hole. Other than the crater, the ground was overgrown with grass. There was no active burning in the crater, although it appeared as if burning had taken place. The grasses showed no evidence of burning, and there was no evidence of debris around the crater rim.

Figure 5

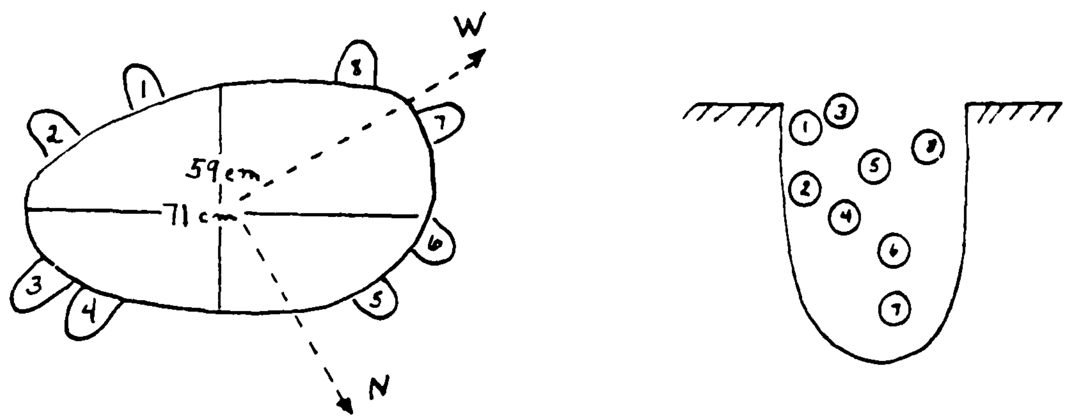


Using a radiological survey meter, measurements of the radiative background were taken within a 3m radius about the hole. No abnormal readings were recorded in or around the crater. To determine the presence, if any, of metallic objects in the crater, a compass was lowered into the hole since no magnetometer was available. No anomalous deflections were noted, indicating an absence of large concentrations of ferrous metal objects or materials.

The crater itself was nearly vertical with a depth of approximately 112cm. The shape of the crater entrance was elliptical with 59cm and 71cm axes. Moving into the crater, eight "off-shoots" or smaller cavities projected radially outward from the crater. The bottom of the crater was covered with loose soil, apparently from "fallback" from the sides. Temperature in the crater did not exhibit any gradients, and averaged approximately 29°C over the entire depth. The majority of the east side of the crater was covered with a whitish/ashen material. The west side was darker but did have some material which appeared fused or melted. There was no immediately apparent reason for formation of the crater.

Figure 6a represents a look "down" the crater. The protrusions around the crater are numbered and their distribution in the vertical is seen in Figure 6b.

Figure 6



a b

Table 1 shows all the information taken on the cavities radiating outward from the crater. Data include depth from surface to center of crater

(Z); approximate angle the cavity makes with horizontal (∂); positive downward depth of cavities (D); temperature at crater opening (T); and direction crater radiates (dir).

Table 1

Hole #	Z (cm)	∂ (deg)	D (cm)	T (°C)	dir (Compass)	Comments
1	28	15	15.2	29.1	S	Charred wood
2a	28	10-15	45.7	28.8	SE	Many ashes
2b	33	20	83.8	28.9	SE	
3	11.43	10-15	22.9	28.4	NE	Charred wood
4	50.8	70	30.5	29.2	NE	Fine ash
5	39.4	0	10.2	29.6	N	
6	63.5	5-10	81.3	29.2	NNW	
7	99.1	5-10	20.3	30.0	W	
8	35.6	-10	17.8	38.3	W	No charring

The soft soil at the bottom of the crater was probed with a steel rod. It was possible to push the rod down 0.5m with little resistance.

After tabulating data and photographing the crater, the AFTAC team collected soil/rock samples from various locations in and around the crater for later analysis. A number of "trash" items were found in the loose soil, including dead vegetation, nail clippers, a key, and a battery.

Local residents were interviewed and no one could verify that the crater existed before the "explosive" sound heard 28 June. Some residents, however, reported that people, including a policeman, had "stuck things" into the hole while it was smoking.

The AFTAC team departed St. Kitts 6 July. Maj Colenda took control of the soil samples and shipped them back to Patrick AFB via military aircraft a week later.

SECTION III

DATA ANALYSIS

The team pursued soil/rock analyses, reviewed potential explanations, and narrowed them into three "classes":

1. Small meteorite--the meteorite would have penetrated the soil and then exploded or buried itself.

2. Small pieces of space junk--as with the meteorite hypothesis, the object would strike the ground at hypervelocities (km/sec), penetrating deep into the soil.

3. Hoax.

Soil analyses could provide verification of the meteorite or space junk hypothesis. Unfortunately, US Department of Agriculture (USDA) regulations prohibit importing soil except to licensed laboratories. The team worked out arrangements with one such laboratory, the Smithsonian Division of Meteorites, Washington DC. Ms Twyla Thomas performed a cursory examination of the soil and saw no evidence of meteorite impact. Ms Thomas' analysis was limited to visual examination of the samples.

AFTAC also arranged for analysis of two rock samples brought back from St. Kitts. Examinations by Walter C. McCrone Associates, Inc., and Aerospace Corporation determined that the rocks were of island origin and not extraterrestrial.

The most comprehensive analysis was performed by the Planetary Materials Branch of the NASA Johnson Space Center's Solar System Exploration Division.

Dr Michael Zolensky, the nation's meteorite expert, analyzed all the soil samples and found no evidence of meteoric material.

A number of other individuals were contacted in order to gain some insight into either the meteorite or space debris possibilities. One of the first contacts was with Dr Mike Sulzer, a chief scientist at the Arecibo, Puerto Rico, antenna facility. An extraterrestrial object entering the earth's atmosphere towards the Caribbean should have registered at the Arecibo facility. Unfortunately, the facility was shut down the evening of 28 June 1986.

Two known earth-penetrator groups were also contacted. Grant Heiken, Los Alamos National Laboratory, identified the hole as a possible, but highly doubtful hypervelocity earth-penetrator hole. Mr Heiken claimed a detailed knowledge of the West Indies and felt that our description almost matched what he termed a "tree mold," *which is the hole dug about a tree* root to burn it out. This practice, he added, is very common on the Caribbean Islands.

Wayne Young of the Earth Penetrator Group at Sandia National Laboratories also identified the crater as possibly due to hypervelocity impact. He provided us a depth penetration equation which his organization uses:

$$D = .0031 \cdot S \cdot N \cdot \sqrt{\frac{W}{A}} \cdot (V-100)$$

Here, D is the depth of penetration into the soil in feet; S is an empirical quantity representing the compactness of the soil (common soil, S=8); N is the aerodynamic "quality" of the penetrating object (flat-ended cylinder, N=.6; aerodynamic shape (conical) N=1); W is the weight of the object in pounds; A is the cross-sectional area of the object in square inches; and V is the velocity of the object in feet/second.

Given the St. Kitts hole depth as 112cm (3.7 ft), and assuming a penetrator with N=.6, W=11 lbs, A=9in^2 and a common soil where S=8, then the velocity would be approximately 110 m/sec. This velocity is close to expected terminal velocities for incoming small (~5kg) meteorites.

The appendix to this report is a rough translation of a Chinese physics journal article on the Jilin Meteorite Shower that occurred in the PRC sometime in 1976. The Jilin shower was the result of an apparent breakup of a large (4,000 kg) meteoroid in the earth's atmosphere. The six resultant pieces spread out as they approached ground, with the final piece landing 50km from the first.

Of interest in this article are the observations on the impact craters. Data is given on crater radius, depth, and angle of impact. In addition, the authors created a model to determine theoretical impact parameters. Table 2 lists the data which correspond to an impact angle near 90° (from horizontal).

Table 2

Jilin Shower Observations and Models

Mass (kg)	Crater Angle (obs)	Crater Angle (cal)	Crater Radius (m)	Crater Depth (m)	Calculation of Impact Velocity (m/sec)	Meteorite Radius (m)
124	55	81	1.0	.3	196	.2
70	-	85	-	-	179	.16
15	93	93	.4	.7	135	.1
.5	0	94	-	-	73	.003

The Sandia depth penetration velocity calculation matches well with the Jilin impact velocity calculations, but the crater depths are shallower than the St. Kitts hole. Even the largest Jilin meteorite penetrated only a third of a meter.

SECTION IV

CONCLUSION

Of the original three hypotheses: a meteorite, a man-made space object, or a hoax, it appears that a hoax is the most probable cause of the St. Kitts mystery hole.

Based upon detailed chemical and spectroscopic analysis, a meteoric impact did not occur. And, although it cannot be completely ruled out, a man-made space object can be doubted based both on the chemical analysis and the USSPACECOM report.

Unless a full excavation of the St. Kitts mystery hole takes place, a complete explanation may never be known, but it is most probably of man-made origin.

APPENDIX

ATMOSPHERIC TRAJECTORY PREDICTIONS AND OBSERVATION ANALYSIS OF THE "JILIN METEORITE SHOWER"

Zhang Deliang   Liu Yukui   Zhao Chengfu (?)

Translated by Dr. Francis Tsang
Edited by J. Nicholas

Introduction

This paper describes a large meteorite from space entering the earth's atmosphere. Due to its high velocity, a very forward peaking 'shock-wave' was created. When this wave reached the ground, this was usually the thunder or explosion heard by people. At the same time, the forward section of the meteoroid was under intense pressure and compression and therefore began to heat up. For example, when the meteoroid reached 20km altitude, its velocity could reach about 10-15km/sec. This could heat up the air surrounding the meteoroid to over 10,000 degrees. Typically, thousands of degrees are not uncommon. Therefore after reaching a certain heating rate, the meteoroid would burn, break-up, and vaporize, forming a very bright fireball.

Rock-type meteoroid's heat transfer characteristics are not very good. This leads to an uneven temperature gradient through the body. The heating and the air pressure cause the surfaces of the meteoroid to crack and the interior to break-up. This is the reason for the break-up of a large meteoroid. A break-up of a large meteoroid would generate many pieces, with the larger ones weighing several tons and the smaller ones weighing less than a kg.

If, after break-up, all the pieces are equal in mass, then their trajectories are the same. Generally speaking, the larger the mass of the meteorite, the longer its flight path and the higher its impact velocity. This is the reason that meteorites with different masses would arrive at different locations with different speeds, and they would form a scattered pattern. This is the meteorite phenomenon.

(The entire text was not translated but the data, results, and assumptions were reviewed and they follow. In a nutshell, this paper analyzes the 'Jilin' meteorite shower and compares the measured impact parameters with a model. The results match up well.-ed.)

We define the meteorite's positions as #1 being the 2000kg, #2 the 400kg, #3;124kg, #4;70kg, #5;15kg, and #6 the .5kg meteorite.(Apparently these designations are based on the landing pattern of the meteorites. On a line running almost due west to east, #1 was furthest west, then #2, etc.-ed.)Density is approximately $3.88 gm/cm^3$.

ASSUMPTIONS:

1. Assume all meteorites are spheres, then mass=$m=4(\pi R^3 p)/3$, cross sectional area=$S=\pi R^2$, p=density, R=radius.
2. No change in density during flight.
3. Ignore the spin of the earth during flight.
4. Meteoroid break-up under intense heat and pressure generating meteorites from 1 to 6. These meteorites continue along the original flight path. Ignore the slight change of speeds and angle offsets due to the break-up.
5. Earth surface is flat.("All that work for nothing", Magellan once said.-ed.)
6. Atmosphere is 70km thick.

Note: Someone had altered the crater angle of #5.

OBSERVATIONS

	mass	vol	R	S	S/m	L	r	h	a	t
	kg	m^3	m	m^2	m^2/kg	m	m	m	deg	
1	2,000	5.154×10^{-4}	4.974×10^{-1}	7.773×10^{-1}	3.886×10^{-4}	0	2.0	6.5	42	15 2 36
2	400	1.031×10^{-1}	2.909×10^{-1}	2.559×10^{-1}	6.645×10^{-4}	1.29×10^{4}	1.5	.5	55	-
3	124	3.196×10^{-2}	1.969×10^{-1}	1.218×10^{-1}	9.822×10^{-4}	1.65×10^{4}	1.0	.3	55	-
4	70	1.804×10^{-2}	1.627×10^{-1}	8.314×10^{-2}	1.188×10^{-3}	1.95×10^{4}	-	-	-	-
5	15	3.866×10^{-3}	9.736×10^{-2}	2.978×10^{-3}	1.965×10^{-5}	2.96×10^{4}	.4	.7	93	-
6	.5	1.299×10^{-4}	3.134×10^{-3}	3.085×10^{-3}	6.169×10^{-5}	4×10^{4} 5×10^{4}	-	-	-	-

Note: L = Distance to landing location with #1 as reference
r=Crater radius
h=Crater depth
a=Crater angle(wrt horizontal)
t= time of impact(only #1 is known, @15hr,02min,36sec)

The apparent parameters for the original meteoroid are:

m=4,000kg
vol=1.031m^3
R=6.268x10^{-1}m
S=1.234m^2
S/m=3.084x10^{-4}

Flight Path: Base Calculation

(The authors then go through the basic physics for flight path calculations.-ed.)
Assume hydrostatic atmosphere and a wind velocity (u_0) profile which behaves as:

u_0= 3+.005H when H<10^{4}m
80-.0027H when 10^4<H<3x10^{4}m
0 when H>3x10^{4}m Where H is altitude in meters

(This behavior was based upon apparent soundings which were taken in the area.-ed.)
The drag coefficient(C_d) behaves as:

.95 when M>1.3
C_d= .75M-0.25 when 0.7<M<1.3
.5 when M<0.7 Where $M=(((u+u_0)^2 + v^2)^{1/2})/340$m/sec. u and v are the x-component and y-component of the meteoroid's velocity respectively.

(M is apparently the Mach number using a constant sound velocity of about 340m/sec.. C_d behavior was also based upon empirical data.-ed.)

(Using their model, the authors then make calculations with the original measured parameters of the found meteorites to establish what they can about the original large meteoroid before break-up. These calculations are presented in the paper in tabular format and are reproduced below.-ed.)

(Table 2.1 assumes a 4,000kg meteoroid enters earth's atmosphere at t=0 and speed=19km/sec. I don't know why the mass of meteorite #2 is listed as 220kg.-ed.)

Table 2.1

meteoroid mass	4000kg					
initial condition	t=0. Ho=70km. ao=16 15'. wo=19km/sec					
break-up cond.	to=9.87 xo=172.71 yo=50.79 Ho=19.21 Vo=14.24 ao=16 33'					
masses(kg)	2.000	220	124	70	15	0.5
Calculated impact parameters t(sec)	40.92	61.39	66.62	72.13	89.96	152.53
L(km)	229.93	217.29	213.72	210.20	201.04	184.25
w(m/sec)	234.1	210.5	195.1	178.7	135.1	72.9
a(deg)	42 38'	74 57'	80 35'	85 14'	93	94 35'
Calculated ΔL	0	12.64	16.21	19.73	28.89	45.68
Measured ΔL	0	12.80	16.50	19.50	28.60	40-50
Difference	0	-.16	-.29	.23	.29	-
Calculated a	42 38'	74 57'	80 35'	85 14'	93	94 35'
Measured a	42	55	55	-	93	-
Difference	38'	19 57'	25 35'	-	0	-

(Table 2.2 assumes a 4,000kg meteoroid enters the earth's atmosphere at t=0 and a speed of 15km/sec.-ed.)

Table 2.2

meteoroid mass	4000kg					
initial condition	t=0. Ho=70km. ao=16 15'. wo=15km/sec					
break-up cond.	to=12.25.xo=169.83.yo=50.20.Ho=19.80.wo=11.55.ao=16 43'					
masses(kg)	2.000	220	124	70	15	0.5
Calculated impact parameters t(sec)	46.05	66.05	71.2	76.65	94.55	157.45
L(km)	227.18	214.55	211.02	207.54	198.48	181.78
w(m/sec)	230.4	211.4	195.9	179.1	135.0	72.9
a(deg)	45 7'	75 53'	81 12'	85 41'	93 7'	94 33'
Calculated ΔL	0	12.63	16.16	19.65	28.70	45.40
Measured ΔL	0	12.80	16.50	19.50	28.60	40-50
Difference	0	-.17	-.34	.15	.10	-
Calculated a	45 7'	75 53'	81 12'	85 41'	93 7'	94 33'
Measured a	45	55	55	-	93	-
Difference	7'	20 53'	26 12'	-	7'	-

Results: 1. If #1 landed with an angle equal to 42deg, see table 2.1.

2. If #1 landed with an angle equal to 45deg, see table 2.2.

3. If the atmospheric entry angle, a_0, is 16 15', entry speed, w_0, is 15km/sec, the trajectory would look like that in figures 5 and 6 (see attached.-ed.). Due to the small differences between calculations and observations, we can conclude that the shower trajectory is the result of an incoming meteoroid with the following characteristics:

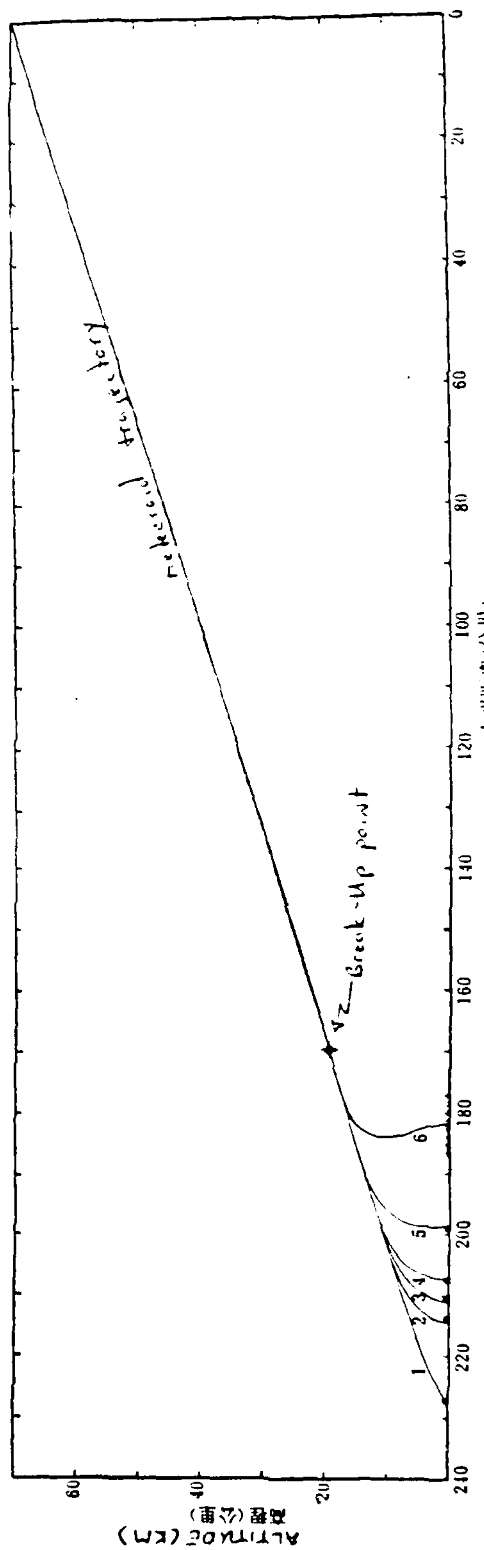


图 5 "吉林陨石雨"飞行轨道(一)

($\alpha_0 = 16°15'$ $W_0 = 15$公里/秒)

——飞行轨道计算结果 ●陨石落地实测结果

◆陨星体分离点位置

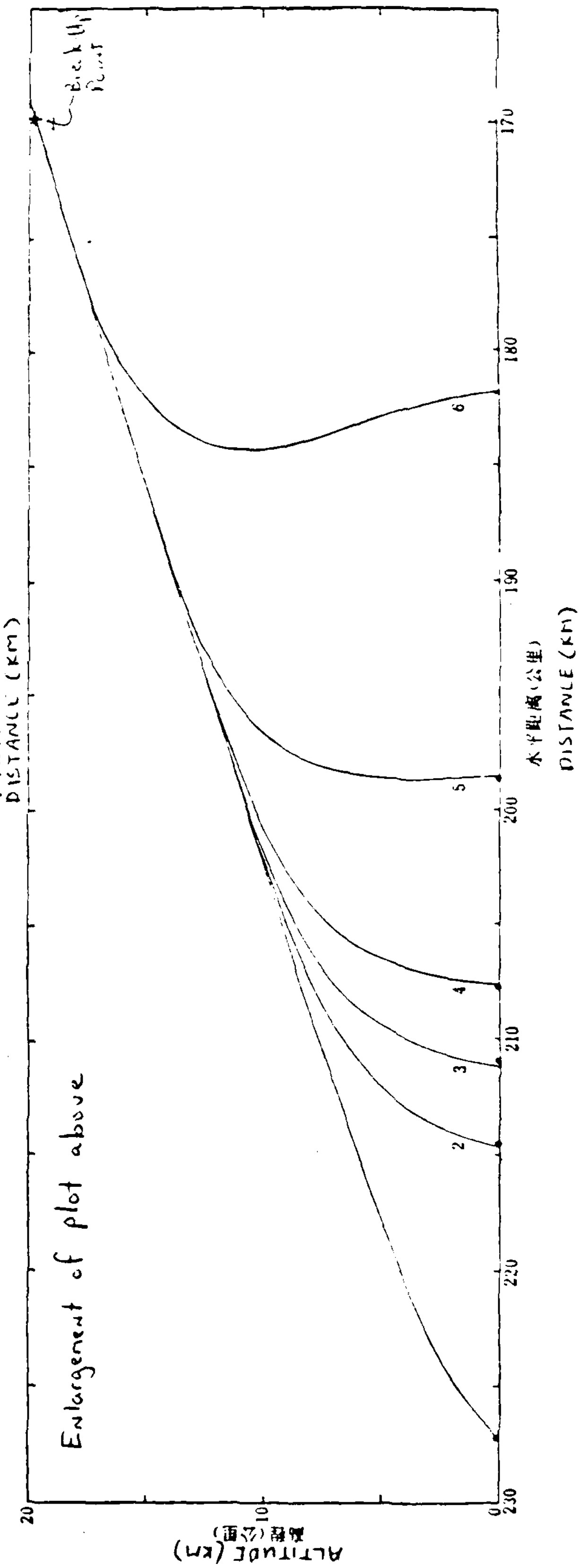


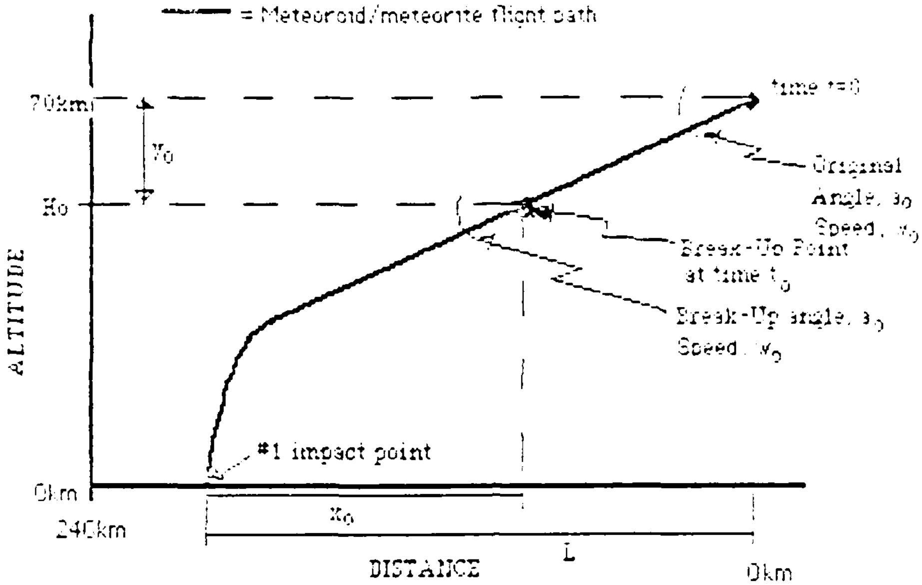
图 6 "吉林陨石雨"飞行轨道(二)

——飞行轨道计算结果 ●陨石落地实测结果

◆陨星体分离点位置

Angle of reentry=16deg 15'
Initial speed= 19-15km/sec
Horizontal distance break-up occurred from impact crater= 57.21-57.36km
Break-up altitude= 19.21-19.81km

(Dr Tsang offers the following diagram to explain all the parameters.-ed.)



(End of Dr Tsang plot.-ed.)

Explanation

At 15hr 1min and 50-55sec the meteoroid entered the earth's atmosphere at an entry angle of 16deg15', with an initial speed of 15km/sec. The meteoroid broke-up above the Chinese province of ______ at 15hr 2min 2 to 5 sec, and #1 meteorite impacted in Jilin at 15hr 2min 36sec. #1 spent about 41 to 46sec in flight and traveled about 227 to 230km from entry into the atmosphere.

#1's landing speed was approximately 280m/sec, mach 1. #6, weighing about .5kg, impacted at approximately 72.9m/sec, almost floating to the ground.

Impact Angle: The calculated impact angle, a_0, as seen in 2.1 and 2.2, actually increases from #1 to #4, and #5 and #6 are actually inclined towards the in the opposite direction.

The results of the calculations indicate that #1 and #5 impact angles and locations are very close to actual observations. Discrepancies for #2 and #3 are rather large. #1 data is credible because the incoming velocity was very large and the soil was rather soft, resulting in a very deep crater(the impact angle was not significantly altered by local inhabitants). #5 impact angle and distance represent a more realistic condition. Based on the #1 and #5 data the model seems to fit rather well, even though the impact angles may not match exactly.

#2 and #3 have different conditions. They have rather shallow craters(#2-.5m deep and #3-.3m deep) and the diameter(#2-.7m and #3-.5m) and the impact angles were rather difficult to measure. Based on our best estimate, #2 impact angle is ~74deg 56'-75deg 53' and #3 is ~80deg 34'-81deg 41'.

Wind Direction

The wind direction can have a big impact on smaller meteorites and even change the impact angle.

(The article goes on to review and compare these results with another model and points out that these results match this model very well. Further, the authors present earth entry parameters calculated, via their model, for other heights, angles and speeds of atmospheric entry. All leading up to the fact that what they said earlier is correct.-ed.)

When the meteoroid reaches 15km/sec when entering the atmosphere, it compresses the air molecules in front of its path forming a very sharply peaked 'shock wave' and substantially raises the temperature of the air. When the meteoroid reaches the break-up location, its speed is between 11.55-14.21km/sec and the temperature of the air is about 15,000 to 19,000 degrees C. The nitrogen and oxygen molecules dissociate into atomic states and create a plasma around the leading edge of the meteoroid and forms an intense fire-ball. For example, a 4oz meteoroid reachnig the break-up point would release (radiate) 0.326×10^{11}cal/sec. The majority of the energy would be carried away by the air molecules, and only a small portion would be absorbed by the meteoroid. But the absorbed energy is enough to cause heating, burning and sublimation at the surface of the meteoroid. The surface temperature would be 3000 to 3500 degrees C.

Because of the rocky nature of the meteoroid, heat transfer and heat capacity are not very good.................(The authors explain heat capacitance-Dr.Tsang)

From the time it enters the atmosphere to the time it breaks up requires about 10sec, and the heat energy reaches about 1cm into the meteoroid. This explains why the heat absorbed by the meteoroid is concentrated on the surface and the center remains very,very cold. This uneven heat distribution creates a large gradient across the meteoroid and a substantial pressure within the core. The pressure could reach 1000 kT(Torr?)/cm^2. At the same time the pressure on

the surface of the meteoroid is around 135-180kT/cm^2. Due to the internal stress and its outer surface pressure, the core of the meteoroid will fracture and cause the break-up. The core can usually withstand internal pressures of a couple of hundred kT/cm^2 before breaking up.

The energy released by the break-up of the meteoroid is not very large. Our estimate of the released energy is $\sigma\epsilon/\rho = 0.258 \times 10^6$ erg/gm, σ is the resistivity $\sim 10^2$ to 10^3 kT/cm^2, ϵ is the rate of change during break-up, and ρ is the density. The total release energy is only of the order of 1.032×10^{12} erg, or about 24.7gm of TNT. The loud boom is not from the meteoroid break-up into meteorites, but is due to the impact of the shock wave on the ground.

If the meteorites burn up in the atmosphere and the wave reaches the ground, a small crater will still be formed based on the angle and mass of the meteoroid and its break-up location.

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